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RADIO ASTROMETRY

Dr. Kenneth J. Johnston
E. O. Hulburt Center for Space Research
Naval Research Laboratory

ABSTRACT

Conventional and VLBI interferometer techniques show promise for accurate determination of UT1, polar motion, and radio source position catalogs.

INTRODUCTION

Radio interferometer measurements of celestial radio sources are being employed to determine variations in the Earth's rotation, polar motion, and a catalogue of radio source positions. Both conventional interferometry and the very long baseline interferometer (VLBI) technique have shown promise in previous experimental tests; the VLBI technique has been demonstrated to determine UT1 to an accuracy of 3 ms, polar motion to submeter accuracy and 0".1 in source catalogue position (Clark and Shapiro 1973; Shapiro et al. 1974), and the conventional technique has been used to determine UT1 to an accuracy of 4.3 ms (Elsmore 1973) and source catalogue position accuracy to 0".1 (Ryle and Elsmore 1973). Further tests are being conducted to evaluate experimental accuracies and atmospheric limitations for different baselines and measurement techniques.

RADIO INTERFEROMETRY

A signal is simultaneously received from a celestial source at two antennas which can be separated by distances of from hundreds of meters to thousands of kilometers. This signal is first mixed to an intermediate frequency. The signal at one of the antennas is delayed by τ_g, the geometric delay or the difference in the doppler shift to the source as seen from the two sites. Finally the signals are cross-correlated. The cross-correlated signal has an amplitude and phase. When the source size is small compared with the interferometer fringe spacing, the normalized correlation amplitude is unity. The phase of the cross-correlated signal yields information on where the source is located in the fringe pattern of the interferometer. One can visualize a pattern of lines or fringes projected onto the sky. As the earth rotates the source passes through this pattern. The phase of the cross-correlated signal changes by 2π radians from fringe to fringe. The separation of the

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fringes on the sky is simply

$$\Delta \theta = \frac{\lambda}{D \sin \theta} \text{ radians,}$$

where λ is the wavelength of the signal, D is the separation of the antennas and θ is the angle between the celestial source and the baseline. See figure 1.

The phase can be determined accurately to a fraction of a fringe in conventional interferometry and precise positions can be determined with a short baseline. For example a 5 km baseline operating at a frequency of 5 GHz, has a fringe spacing of 2".5. A determination of the phase of a celestial source to 5° results in a position accuracy of 0.035 arc seconds or 2 milliseconds.

The difference between VLBI and conventional interferometry is in the phase stability of the interferometer. Conventional interferometers offer phase stabilities of a few degrees for periods of days. The principal limitations to phase stability at frequencies above 5 GHz are short period variations in atmospheric refractivity and instrumental phase variations. VLBI on the other hand depends on independent local oscillators controlled by atomic frequency standards at the two locations, and has phase instabilities of several radians in a period of an hour. The principal limitation to phase stability is the frequency stability of the standards at each site used to generate the local oscillator chains. These L.O. chains are used to mix the signal down to an intermediate low frequency that can be recorded on magnetic tape.

Since VLBI has poor phase stability, the phase of the signal is not analyzed directly but rather its derivatives, delay which is the rate of change of phase with frequency, and fringe rate which is the rate of change of phase with respect to time. Thus for the same baseline, conventional interferometry will be orders of magnitude more accurate than VLBI. The very long baselines possible with VLBI, however, compensate for this difference in precision.

The major limitations to conventional interferometry are:

1) Short term changes in atmospheric phase path, i.e. the signal from the celestial source does not pass through identical atmospheric paths to the antennas. Small scale variations in atmospheric refractivity due mainly to water vapor cause the atmospheric phase path to vary in a random

manner on the order of minutes. Present data on the rms variation in atmospheric path length is very incomplete, but the trend is displayed versus baseline length in figure 2. The single point at 35 km is preliminary information from Wade (1974) of the National Radio Astronomy Observatory where the antennas were connected by a radio link. There is a marked difference between the phase path deviations on a summer day versus a winter day. The summer nights and winter nights resemble the winter day. Therefore observations obtained during a summer day would be expected to have one half the accuracy of those made at night or on a winter day.

2) Instrumental noise--If the antennas are connected by a radio link, noise over this link may contribute significantly to the data. There may also be significant noise contribution by noise generated in the local oscillator system. Temperature effects on the cables connecting the individual antennas and the delay lines also contribute to the system phase noise.

COMPARISON OF TECHNIQUES

The accuracy of conventional interferometry and VLBI in determining UT1 has been estimated. From figure 2, an estimate may be made of the contribution of short term changes in atmospheric refractivity to phase noise. Assuming this to be the major contributor to phase noise, the accuracy in the determination of UT1 may be predicted, and is displayed in figure 3 versus equatorial baseline.

In work done in collaboration with C. M. Wade and R. M. Hjellming of the National Radio Astronomy Observatory (NRAO) preliminary observations have been obtained over a baseline of 35 kilometers. The operating frequency was 2695 MHz (11.1 cm). The baseline is located on an azimuth angle of about -45°. Observations were obtained of 16 radio sources over a five day period in January 1974. From the observed phases, corrections to the equatorial and polar baselines, and source coordinates were calculated by least squares. This solution resulted in an rms phase noise of 16°. This is equivalent to a position accuracy of 0.″029 or 2 ms. For individual source coordinates, the accuracy depends on the baseline geometry and source declination. For a given baseline, there is a definite correlation versus source declination. The solution for right ascension and declination are not correlated for sources near the zenith. Therefore, observations of a source that transits through the zenith will yield the most accurate measurement of UT1.

This is attested to by the fact that the solution of this set of data for the right ascension of 3C84 ($\delta = 40°$) resulted in an internal accuracy of 2 ms.

The accuracies of the VLBI technique in fringe rate and time delay are calculated assuming an accuracy of 1×10^{-13} parts in fringe rate residuals (Moran et al. 1973; Cohen 1971) and an accuracy of 10^{-9} seconds in delay. The data by Shapiro (1974) agree well with this. Therefore at the present time conventional interferometry and VLBI offer similar accuracies in determining UT1.

Some of the advantages of the conventional interferometry technique over VLBI are:

1) Variations in atmospheric refractivity--the conventional technique is less influenced by variations in atmospheric refractivity since the antennas are located closer together and see more nearly the same atmospheric path conditions.

2) Solid Body Earth Tides--the relative effect of solid body Earth tides between the antennas of a conventional interferometer is negligible whereas for VLBI it is not.

3) Frequency Standards--there is no need for highly stable and precise frequency standards in a conventional interferometer, whereas VLBI requires hydrogen maser frequency standards and clock synchronization to a microsecond.

4) Data Reduction--the data may be reduced in real time. After a day's observation, UT and polar motion may be calculated immediately. There is no need to correlate magnetic tapes from widely separated locations to obtain correlation functions.

5) Station Management--it is much easier to manage stations that are 10-100 km apart than thousands of km apart.

PLANS

Conventional interferometry will be investigated initially through evaluation of observations obtained with the NRAO interferometer and VLBI techniques will be further evaluated. These data will define basic accuracy limitations and guide the design of optimum techniques for radio astrometry.

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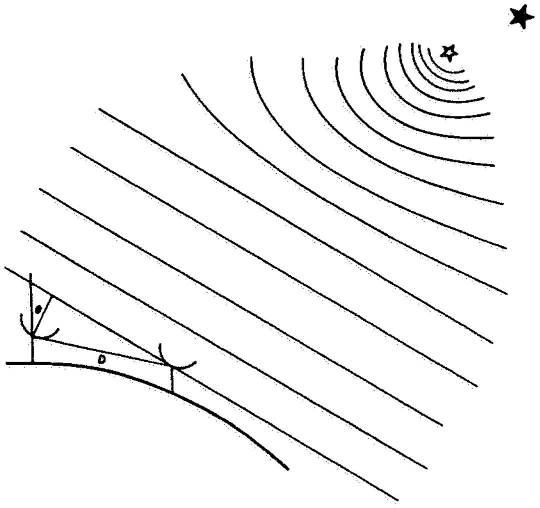

Fig. 1-Celestial Source and Antenna Configuration

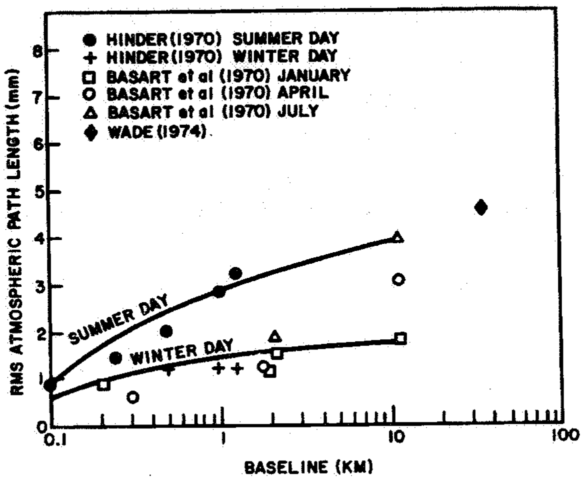

Fig: 2-Variation of RMS Path-length With Baseline

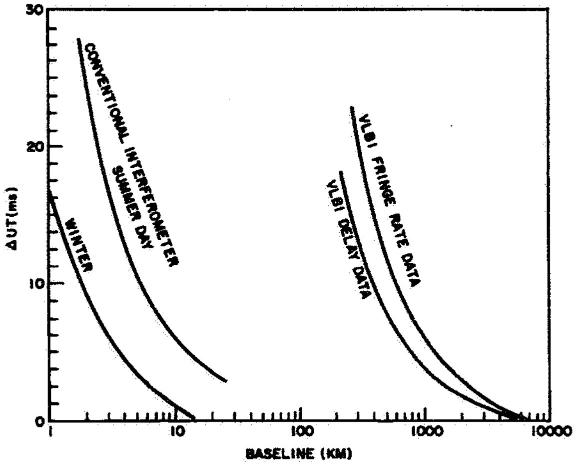

Fig. 3-Accuracy in UT1 Determination Versus Equatorial Baseline

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